CLAIM AMENDMENTS

~~I~~ We claim:

1. (Currently Amended) ~~In a~~ A device for producing quantum effects, comprising:

~~(a)~~ a material fashioned into an elongated fiber shape~~, as in a wire, ribbon, or optical fiber;~~,

~~(b)~~ one or more control paths which carry energy along said ~~fiber~~ material;

~~(c)~~ a plurality of quantum dots, ~~whether particles, devices, or other types, on or near the surface of the fiber, which~~ physically connected with said material and energetically connected to said control paths; wherein

the energy carried in said control paths actuate the quantum dots to trap and hold a controlled configuration of charge carriers ~~based on the energy or energies in said control paths~~, thus forming artificial atoms whose size, shape, atomic number and energy level are dependent on the energies in said control paths

~~whereby said fiber can serve as a substitute for quantum dots and quantum wires in existing and future applications, and~~

~~whereby the electrical, optical and possibly other properties such as magnetic, mechanical, and chemical properties of said fiber can be manipulated through adjustment of the energies in the control paths, and~~

~~whereby said fiber can be embedded inside a bulk material, to serve as a programmable dopant which is capable of altering the electrical, optical and possibly other properties of said material in real time based on the energies in said control paths, and~~

~~whereby a plurality of said fibers can be woven, braided, or otherwise arranged into two- or three-dimensional structures, creating materials whose characteristics are electrically or optically programmable in real time by means of the energies in said control paths~~.

2. (Currently Amended) The device of Claim 1, wherein said control paths are electrical wires, whether conductors, semiconductors, or superconductors, which ~~carry~~ create electrical ~~voltages~~ potentials across the quantum dots.

3. (Currently Amended) The device of Claim 1, wherein said control paths are optical fibers carrying light or laser energy.

4. (Currently Amended) The device of Claim 1, wherein said control paths are radio frequency or microwave antennas.

5. (Currently Amended) The device of Claim 1, wherein the quantum dots are quantum dot particles.

6. (Currently Amended) The device of Claim 1, wherein the quantum dots are quantum dot devices.

7. (Currently Amended) ~~In a~~ A method for controlling dopants in the interior of a bulk ~~materials~~ material in real time, after a time of initial manufacture, the method comprising:

~~(a)~~ confining charge carriers in the bulk material in a dimension smaller than the de Broglie wavelength of said charge carriers, such that the charge carriers assume a quantum wavelike behavior in all three dimensions in at least one confinement region;

~~(b)~~ carrying ~~electrical or other~~ energy through ~~conduits~~ at least one conduit in said solid material to said charge carriers ~~while embedded in a solid material~~ in the at least one confinement region, without said energy directly contacting said solid material except through said ~~carriers~~ at least one conduit; and

controlling said energy so that artificial atoms are formed by the charge carriers in the confinement region, whose properties can be adjusted in real time;

whereby said ~~carriers form configurations such as~~ artificial atoms ~~whose properties are controlled in real time, and which are capable of serving~~ serve as programmable dopants to alter the electrical, optical, ~~and possibly other properties such as~~ thermal, magnetic, mechanical, and chemical properties[[,]] of said bulk material in real time~~, and~~

~~whereby a plurality of said methods can be combined, creating a means for producing materials whose electrical, optical, and possibly other properties such as magnetic, mechanical, and chemical properties can be adjusted in real time~~.

8. (Currently amended) The method of Claim ~~6~~ 7, wherein the ~~means~~ step of confining said charge carriers further comprises:

attaching a is a plurality of quantum dot particles or quantum dot devices to the bulk material[[,]]; and

energetically connecting said ~~conduits are consolidated into fibers to which~~ said quantum dot particles or quantum dot devices ~~are attached~~ with said at least on conduit.

9. (New) The device of Claim 1, wherein only the atomic number and energy level of the artificial atoms can be controlled.

10. (New) The device of Claim 1, wherein only the energy level of the artificial atoms can be controlled.

11. (New) The device of claim 1, wherein the material further comprises:

a first barrier layer;

a second barrier layer;

a transport layer located between the first barrier layer and the second barrier layer; and

a plurality of electrodes connected with the control paths; wherein

when energized, the plurality of electrodes interact with the first barrier layer, the second barrier layer, and the transport layer to create at least one quantum well that functions as a quantum dot device.

12. (New) The device of claim 1, wherein the material further comprises a memory layer that switches the energy carried to a first confinement region from a first one to a second one of the one or more control paths.

13. (New) The device of claim 1, wherein said one or more control paths comprises a single wire.

14. (New) The device of claim 1 further comprising an insulating medium, wherein said one or more control paths are positioned in said insulating medium and insulated from each other.

15. (New) The device of claim 1, wherein said solid material is embedded inside a bulk material, serving as a programmable dopant capable of altering the electrical, optical, thermal, magnetic, mechanical, and chemical properties of said bulk material in real time based on the energies in said control paths.

16. (New) The device of claim 1, wherein said device comprises a plurality of fibers of said solid material woven, braided, ,stacked or otherwise arranged into two- or three-dimensional structures.

17. (New) The device of claim 1, wherein said fiber shape is of a shape selected from the group consisting of: a wire, a ribbon, and an optical fiber.

DRAWING AMENDMENTS

A complete set of new drawing sheets is filed herewith including prior art Figures 1, 2, 3A and 3B that were originally included in the body of the written description.

Figure 4c is added to provide additional clarity to the written description of the memory layer of the invention.

The drawing sheets are renumbered to reflect the addition of three sheets to accommodate Figures 1, 2, 3A, 3B, and 4c.

REMARKS/ARGUMENTS

Applicants request the Office consider the following remarks upon its further review of the instant application. The invention of the present application is

Specification Amendments

The application document has been reorganized to conform to the Office's preferred layout. A substitute specification is provided herewith as Applicants' changes involved relocating large sections of text throughout the application, which would make normal amendment practice difficult to follow. These additions and deletions do not change to the content of the specification, and should not be interpreted as new matter. Support in the original specification for certain paragraphs in the substitute specification is detailed below.

Paragraph [0007] is a general definition of the term "dopant," well known to one of ordinary skill in the art, and is provided to clarify the use of the term as it is used in the application.

Paragraphs [0020] – [0023] find support in the claims as presented in the original specification.

Additional language in paragraph [0037] of the substitute specification finds support in Figures 4a and 4b and on pages 3, 10, and 11 of the original specification.

Paragraph [0040] of the substitute specification finds support on pages 8 and 14 of the original specification.

Paragraph [0041] of the substitute specification finds support on page 12 of the original specification.

Additional language in paragraph [0042] of the substitute specification finds support on page 11 of the original specification.

Paragraphs [0044] – [0047] originally appeared under the heading "Operation – Figs. 4a and 4b" on pages 14-15 of the original specification.

Paragraph [0049] of the substitute specification finds support on pages 3, 7, and 10 of the original specification.

Paragraphs [0050] – [0052] of the substitute specification originally appeared under the heading "Operation – Figs. 5a and 5b" on page 15 of the original specification.

Paragraph [0054] of the substitute specification finds support on pages 3, 7, and 10 of the original specification.

Paragraphs [0055] – [0056] of the substitute specification originally appeared under the heading "Operation – Figs. 6a and 6b" on pages 15-16 of the original specification.

Paragraph [0058] of the substitute specification finds support on pages 3, 7, 10, and 16 of the original specification.

Paragraphs [0059] – [0060] of the substitute specification originally appeared under the heading "Operation – Figs. 7a and 7b" on page 16 of the original specification.

The additional language and paragraphs discussed above are provided for the purpose of increasing the specificity of the disclosure without affecting the nature, structure, composition or function of the invention. Applicants believe the amendments to the specification to be fully supported by the original disclosure.

Applicants also provide new Figure 4c clarifying the structure of the optional memory layer originally described on pages 11 and 14 of the application. Corresponding descriptive text has been added to the specification for clarity. This figure and its description merely provide additional description of a feature fully supported by the original specification. Since the figure has the effect of increasing the specificity of the disclosure without affecting the nature, structure, composition, or function of the invention, Applicants do not consider it to be new matter.

Claim Amendments

Claim 1 is amended to broaden the scope of the claim, to correct problems with antecedent basis between the terms, and to remove the whereby clauses that merely describe the functional effects of the claimed device.

Claim 2 is amended to correct a grammatical error by adding a period to the end of the claim and to provide correct electrical terminology with respect to what is carried by a wire.

Claims 3-6 are amended to correct grammatical errors by adding commas, periods, or both as necessary.

Claim 7 is amended to amended to broaden the scope of the claim, to correct problems with antecedent basis between the terms, to clarify that the dopant effects can be manipulated in real time, and to remove the whereby clauses that merely provide superfluous description.

Claim 8 is amended to restate its substance in the form of a method claim.

Claims 9-17 are newly added by this amendment and are believed to be fully supported by the specification.

Priority

The Office action indicates the claimed priority filing date of provisional application 60/312,264 as referenced in the present application is not consistent with Office records. The Cross-Reference section of the specification has been changed from 13 August 2001, an incorrect value, to14 August 2001, which should conform to the Office records.

Information Disclosure Statement

The Office action indicates that reference AX entitled "Overview of Nanoelectronic Devices" submitted with an information disclosure statement dated 26 September 2001 fails to comply with 37 C.F.R. §§ 1.97 & 1.98 because the reference submitted was incomplete. All of the relevant pages of this reference are enclosed herewith as part of a new information disclosure statement and form 1449. An appropriate fee for submission of the reference after receipt of the first Office action is also enclosed.

Drawing Amendments

The Office action indicates corrected drawings are required in this application because Figures 1, 2, 3A and 3B are included in the written description. A complete set of new drawing sheets is filed herewith including prior art Figures 1, 2, 3A and 3B that were originally included in the body of the written description.

Specification Objections

The Office action objects to the specification, including the abstract, because of the misspelling of words throughout, the inappropriate preamble to the claims, and the layout of the specification. A substitute specification pursuant to 37 C.F.R. § 1.125 is enclosed herewith that corrects the misspellings, the preamble to the claims, and the layout of the specification in general.

The Office action further objects to the title as not being descriptive of the invention as claimed. Applicants have amended the title of the invention to more accurately conform to the scope of the claims.

Claim Objections

The Office action objects to claims 1, 2, and 5-7 due to certain informalities in grammar and punctuation. These informalities have been corrected.

Claim Rejections for Indefiniteness – 35 U.S.C. § 112

The Office action rejects Claims 1-8 as being indefinite for failing to particularly point out and distinctly claim the subject matter which the Applicants regard as the invention.

The Office action states in particular that claims1 and 7 are vague and indefinite and that it is unclear to a person having ordinary skill in the art as to how the device for producing quantum effects, or the method for controlling dopants in the interior of bulk materials, would work. These assertions are made without any explanation of who the Office would consider to be a person of ordinary skill and further why the present application would be unclear to such a person. See M.P.E.P. §2163 generally and § 2163.04. The Office has therefore failed to meet its initial burden in presenting this rejection and therefore the rejection should be withdrawn.

Applicants do not consider the exact design, composition or functioning of a quantum dot device or particle, or the precise mechanisms by which dopants generally operate to alter the behavior of materials, to be part of the invention. For example, the structure, composition, manufacture and functioning of quantum dot particles is taught in U.S. patent application publication no. 2003/0066998 by Lee, cited in the Office action. The structure, composition, manufacture and functioning of quantum dot devices is also taught in U.S. Patent No. 5,889,288 to Futatsugi as described in the instant application. It will be understood by a person of ordinary skill in the art that the quantum dot particles or quantum dot devices employed by the present invention may be of different design than those described by Lee and Futatsugi, but that their operating principles are essentially identical, and are not claimed by Applicants as an invention.

Furthermore, the functioning of quantum dots as dopants is already well established in the prior art, in thin films and on the surfaces of microchips. It is understood that quantum dots can have a greatly modified electronic structure from the corresponding bulk material, and therefore different material properties (for example, optical and electrical). The use of quantum dots as dopants inside other materials is described, for example, in U.S. patent application publication no. 2002/0041736 by LoCasclo et al. at paragraph 0045. The term "artificial atom" is also in common use, for example, in U.S. Patent 6,498,354 to Jefferson et al., and is often used interchangeably with "quantum dot." Kouwenhoven et. al. (1998) describe the process of manipulating an artificial atom confined in a similar device to that described by Futatsagi, including changing its atomic number by varying the voltage on a gate electrode. The described device is capable of holding up to 100 electrons, whose "periodic table" is also described, and is different from the periodic table for normal atoms since the quantum confinement region is nonspherical. The materials science implications of this are not discussed.

Applicants' invention involves the reorganization of certain of these principles and devices, in a novel and useful way, for the specific purpose of forming programmable dopants that can be controlled in real time. With this background, Applicants' invention is specifically a fiber populated with quantum dots (whether particles or devices) attached to or adjacent to the fiber surface and with one or more control wires running through the interior of the fiber to control the doping properties of the quantum dots, even in the interior of bulk materials. This structure has been fully described in the specification and drawings and multiple embodiments have been discussed. Applicants believe this disclosure meets the written description requirements and is enabling to one of ordinary skill in the art.

The Office action further identifies specific language in the claims deemed to be indefinite. All indefinite statements have been removed from the claims as amended herein.

Claim Rejections for Novelty – 35 U.S.C. § 102

Claims 1-6 are rejected in the Office action under 35 U.S.C. § 102(e) as being anticipated by U.S. Patent No. 6,512,242 to Fan et al. Applicants believe the Office is mistaken in its understanding of Fan et al. and its application to Applicants claims as amended.

Fan et al. discloses a quantum wire used in conjunction with one or more quantum dots located near the quantum wire. The quantum wires transport electrons into and out of the quantum dot or plurality of quantum dots. However, there is no description of a material forming the quantum wire that is an elongated fiber as claimed in the present application. The figures in Fan et al., for example, Figure 5, are merely schematic drawings to represent a "quantum wire" and a "quantum dot." A quantum wire is a quantum well formed on a substrate that allows a confined charge to propagate in only one dimension. Such a one-dimensional quantum well as taught by Fan et al. is formed by using an electronic waveguide on a semiconductor substrate. (See col. 3, ll. 50-65.) Nowhere in the disclosure of Fan is an elongated fiber material disclosed or suggested.

Further, the electron transport in Fan et al. is accomplished through "resonant tunneling" rather than through any direct connection between the quantum wire and the quantum dot. In fact, Fan's diagrams show a definite spatial separation between the quantum dots and the quantum wires. In other words, Fan's invention uses quantum dots which are explicitly detached from the quantum wires, whereas in the present invention the dots are explicitly attached to control paths carrying energy. Further, the control paths of the present invention are not necessarily quantum wires.

This difference has an enormous effect on the functioning of the quantum dots themselves. In the Fan et al. reference, the quantum dots serve not as artificial atoms but as "resonant coupling elements," which transport electrons between electronic waveguides, or between different ports on the same waveguide. In other words, the quantum dot serves only as a pass-through conduit; there is no means for controlling the number of electrons trapped inside the quantum dot at any given time, nor for controlling the size or shape of any artificial atom which might briefly (and incidentally) exist there. Thus, quantum dots described in Fan et al. could not be used as programmable dopants, and the devices disclosed therein could not be used to systematically (i.e., programmably) alter the properties of materials in real time. Nowhere in the disclosure of Fan et al. are these capabilities stated or implied.

For at least these reasons, the rejection in view of the Fan et. al. reference should be withdrawn and claims 1-6, and additionally new claims 9-17, should be allowed.

The Office action further rejects claims 7 and 8 under 35 USC 102(e) as anticipated by U.S. patent application publication no. US 2002/0079485 A1 of Stinz et. al. This reference discloses a "quantum dash" device which can be viewed as an asymmetric quantum dot particle with elongated axes, or as a short, disconnected segment of a quantum wire. Stinz discloses a plurality of these devices embedded at particular locations inside a solid material to alter its properties, specifically to enhance the excitation of laser energy within the material. Arguably the quantum dash devices serve as dopants, although the reference does not refer to them as such, and also makes no reference to "artificial atoms," nor to the number or pattern of charge carriers confined within the dash.

In a very crude sense these dashes are "programmable," since the resulting structure is a "tunable laser" whose output frequency can be adjusted over a narrow range. However, this tuning is accomplished through "wavelength selective feedback," using an external optical grating to limit the input light frequencies which can reach the dashes inside the material. In the only reference to atom-like behavior, the reference states, "an ensemble of uniformly sized quantum dashes that functioned as ideal quantum dots would have an atomic-like density of states and optical gain." Selection of the available quantum states is achieved exclusively at the time of manufacture, "with a variety of length-to-width-to-height ratios, for example, by adjusting the InAs monolayer coverage, growth rate, and temperature."

In other words, Stinz et al. relies on the exact geometry and composition of the quantum dashes to produce artificial atoms of a particular size, shape, and atomic number. While a beam of photons with carefully selected energies can excite these artificial atoms inside the dashes, it cannot alter their fixed size, shape, or atomic number. Moreover, unlike

the claims of the present invention, no conduits are provided in Stinz et al. for transmitting this light energy. As a result, the energy affects all the quantum dashes equally, along with the surrounding material in which they are embedded.

In this sense, quantum dashes are merely a special class of quantum dot particles, and cannot serve as programmable dopants unless additional supporting hardware, not disclosed or suggested by Stinz et al., is provided. It should be noted that the present invention, as described in this application, could employ quantum dashes in the same manner as quantum dot particles, with little change in its essential function.

Furthermore, if the surrounding material is opaque, then photon energy cannot reach Stinz's quantum dashes at all. In contrast, the present invention, which does provide conduits connected with the quantum dots, is capable of controlling dopants inside an opaque material. Nowhere in the Stinz reference disclosure are these capabilities stated or implied. Therefore, Applicants assert Stinz et al. does not anticipate the claims in the present application and request that the rejection of claims 7 and 8 based upon this reference be withdrawn.

Conclusion

Applicants respectfully request that a timely Notice of Allowance be issued in this case.

Respectfully submitted this 24th day of October 2003.

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~~Patent Application of~~

~~Wil McCarthy and Gary E. Snyder~~

~~for~~

~~**QUANTUM DOT FIBER**~~

TITLE

Fiber incorporating quantum dots as programmable dopants

INVENTORS

Wil McCarthy of Lakewood, Colorado

Gary E. Snyder of Lakewood, Colorado

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is entitled to the benefit of Provisional Patent Application ~~Ser.#~~ no. 60/312,264, filed ~~13~~ 14 August 2001.

BACKGROUND [[–]] OF THE INVENTION

1. Field of the Invention

This invention relates to a device for producing quantum effects, namely a fiber that is capable of carrying energy with an ~~whose~~ exterior surface ~~has~~ populated by quantum ~~dots attached to it~~ dot structures that are controlled by changes in the energy carried by the fiber. The invention has particular, but not exclusive, application in materials science[[,]] as a programmable dopant ~~which~~ that can be placed inside bulk materials and controlled by external signals.

~~**BACKGROUND -- DEFINITIONS AND THEORY OF OPERATION**~~

2. Description of the Related Art

The fabrication of very small structures to exploit the quantum mechanical behavior of charge carriers (e.g., electrons or electron "holes") is well established. Quantum confinement of a carrier can be accomplished by a structure whose linear dimension is less than the quantum mechanical wavelength of the carrier. Confinement in a single dimension produces a "quantum well," and confinement in two dimensions produces a "quantum wire."

A quantum dot (QD) is a structure capable of confining carriers in all three dimensions. Quantum dots can be formed as particles, with a dimension in all three directions of less than the de Broglie wavelength of a charge carrier. Such particles may be composed of semiconductor materials (including Si, GaAs, InGaAs, InAlAs, InAs, and other

materials), or of metals, and may or may not possess an insulative coating. Such particles are referred to in this document as "quantum dot particles." A quantum dot can also be formed inside a semiconductor substrate, through electrostatic confinement of the charge carriers. This is accomplished through the use of microelectronic devices of various design, ~~(~~e.g., a nearly enclosed gate electrode formed on top of a quantum well, similar to a P-N-P junction~~)~~. Here, the term "micro" means "very small" and usually expresses a dimension less than the order of microns, i.e., ~~(~~thousandths of a millimeter~~)~~. The term "quantum dot device" refers to any apparatus capable of generating a quantum dot in this manner. The generic term "quantum dot," abbreviated QD in certain drawings in this application, refers to any quantum dot particle or quantum dot device.

The electrical, optical, thermal, magnetic, mechanical, and chemical properties of a material depend on the structure and excitation level of the electron clouds surrounding its atoms and molecules. Doping is the process of embedding precise quantities of carefully selected impurities in a material in order to alter the electronic structure of the surrounding atoms, for example, by donating or borrowing electrons from them, and therefore altering the electrical, optical, thermal, magnetic, mechanical, or chemical properties of the material. Doping levels as low as one dopant atom per million atoms of substrate can produce measurable changes in the expected behavior of the pure material, for example, by altering the band gap of a semiconductor.

Quantum dots can have a greatly modified electronic structure from the corresponding bulk material, and therefore different properties. Quantum dots can also serve as dopants inside other materials. Because of their unique properties, quantum dots are used in a variety of electronic, optical, and electro-optical devices.

Kastner, "Artificial Atoms," Physics Today (January 1993) points out that the quantum dot can be thought of as an "artificial atom," since the carriers confined in it behave similarly in many ways to electrons confined by an atomic nucleus. The term "artificial atom" is now in common use, and is often used interchangeably with "quantum dot." However, for the purposes of this document, "artificial atom" refers specifically to the pattern of confined carriers (e.g., an electron gas), and not to the particle or device in which the carriers are confined.

The term "~~quantum dot~~ programmable dopant fiber" refers to a wire or fiber with quantum dots attached to, embedded in, or ~~forming~~ formed upon its outer surface. This should not be confused with a quantum wire, which is a structure for carrier confinement in two dimensions only.

~~BACKGROUND – DESCRIPTION OF PRIOR ART~~

Quantum dots are currently used as near-monochromatic fluorescent light sources, laser light sources, light detectors (including infra-red detectors), and highly miniaturized transistors, including single-electron transistors. They can also serve as a useful laboratory for exploring the quantum mechanical behavior of confined carriers. Many researchers are exploring the use of quantum dots in artificial materials, and as programmable dopants to affect the optical and electrical properties of semiconductor materials.

Kastner ~~(1993)~~ describes the future potential for "artificial molecules" and "artificial solids" composed of quantum dot particles. Specifics on the design and functioning of these molecules and solids are not provided. Leatherdale et. al., Photoconductivity in CdSe Quantum Dot Solids," Physics Review B (15 July 2000) describe, in detail, the fabrication of "two- and three-dimensional... artificial solids with potentially tunable optical and electrical properties." These solids are composed of colloidal semiconductor nanocrystals ~~desposited~~ deposited on a semiconductor substrate. The result is an ordered, glassy film composed of quantum dot particles, which can be optically stimulated by external light sources, or electrically stimulated by attached electrodes, to alter its optical and electrical properties. However, these films are extremely fragile, and are "three dimensional" only in the sense that they have been made up to several microns thick. In addition, the only parameter ~~which~~ that can be adjusted electrically is the average number of electrons in the quantum dots. Slight variations in the size and composition of the quantum dot particles mean that the number of electrons will vary slightly between dots. However, on average the quantum dot particles will all behave similarly.

The embedding of metal and semiconductor nanoparticles inside bulk materials (e.g., ~~the~~ lead particles in leaded crystal) is also well established. These nanoparticles are quantum dots ~~whose~~ with characteristics ~~are~~ determined by their size and composition~~, and they~~. They also serve as dopants for the material in which they are embedded[[,]] to alter selected optical or electrical properties. However, there is no means or pathway by which these quantum dot particles can be stimulated electrically. Thus, the doping characteristics of the quantum dots are fixed at the time of manufacture and cannot be adjusted thereafter.

~~However~~ In general, the prior art almost completely overlooks the broader materials-science implications of quantum dots. The ability to place programmable dopants in a variety of materials implies a useful control over the bulk properties of these materials. This control could take place not only at the time of fabrication of the material, but also in real time, i.e., at the time of use, in response to changing needs and conditions. However, there is virtually

no prior art discussing the use, placement, or control of programmable quantum dots in the interior of bulk materials. ~~Simiarly~~ Similarly, there is no prior art discussing the placement of quantum dots on the ~~outside~~ surface of an electrically or optically conductive fiber. ~~There are hints of these concepts in a handful of references, discussed below:~~

U.S. ~~patent~~ Patent No. 5,881,200 to Burt (1999) discloses an optical fiber (1) containing a central opening (2) filled with a colloidal solution (3) of quantum dots (4) in a support medium. (See prior art Figures 1 and 2.) The purpose of the quantum dots is to produce light when optically stimulated, for example, to produce optical amplification or laser radiation. The quantum dots take the place of erbium atoms, which can produce optical amplifiers when used as dopants in an optical fiber. This fiber could be embedded inside bulk materials, but could not alter ~~their~~ the properties of such materials since the quantum-dot dopants are enclosed inside the fiber. In addition, no means is described for exciting the quantum dots electrically. Thus the characteristics of the quantum dots are not programmable, except in the sense that their size and composition can be selected at the time of manufacture.

U.S. ~~patent~~ Patent No. 5,889,288 to Futatsugi (1999) discloses a semiconductor quantum dot device ~~which~~ that uses electrostatic repulsion to confine electrons. This device, as shown in prior art Figures 3a and 3b consists of electrodes (16a, 16b, and 17) controlled by a field effect transistor, both formed on the surface of a quantum well on a semi-insulating substrate (11). This arrangement permits the exact number of electrons trapped in the quantum dot (QD) to be controlled, simply by varying the voltage on the gate electrode (G). This is useful, in that it allows the "artificial atom" contained in the quantum dot to take on characteristics similar to any natural atom on the periodic table, ~~including~~ and also to transuranic and asymmetric atoms which cannot easily be created by other means. Unfortunately, the two-dimensional nature of the electrodes means that the ~~quantum dot~~ artificial atom can exist only at or near the surface of the wafer, and cannot serve as a dopant to affect the wafer's interior properties.

Turton, "The Quantum Dot," Oxford University Press (1995) describes the possibility of placing ~~such~~ quantum dot devices in two-dimensional arrays on a semiconductor microchip, explicitly as a method for producing new materials through programmable doping of the substrate. This practice has since become routine, although the spacing of the quantum dot devices is typically large enough that the artificial atoms formed on the chip do not interact significantly, nor produce macroscopically significant doping. Such a chip also

suffers from the limitation cited in the previous paragraph: its two-dimensional structure prevents its being used as a dopant except near the surface of a material or material layer.

Goldhaber-Gordon et[[.]] al., "Overview of Nanoelectronic Devices," Proceedings of the IEEE, v. 85, n.4 (April 1997) describe what may be the smallest possible single-electron transistor. This consists of a "wire" made of conductive C_6 (benzene) molecules, with a "resonant tunneling device" or RTD inline ~~which~~ that consists of a benzene molecule surrounded by CH_2 molecules ~~which~~ that serve as insulators. The device is described (incorrectly, ~~I~~ we believe) as a quantum well rather than a quantum dot, and is intended as a switching device (transistor) rather than a confinement mechanism for charge carriers. However, in principle the device should be capable of containing a small number of excess electrons and thus ~~forming~~ form a primitive sort of artificial atom. Thus, the authors' remark on page 532 that the device may be "much more like a quantum dot than a solid state RTD." The materials science implications of this are not discussed.

McCarthy, "Once Upon a Matter Crushed," Science and Fiction Age (July 1999), in a science fiction story, includes a fanciful description of "wellstone," a form of "programmable matter" made from "a diffuse lattice of crystalline silicon, superfine threads much finer than a human hair," which use "a careful balancing of electrical charges" to confine electrons in free space, adjacent to the threads. This is probably physically impossible, as it would appear to violate Coulomb's Law, although ~~I~~ we do not wish to be bound by this. Similar text by the same author [[~~— myself —~~]]appears in McCarthy, The Collapsium," Del Rey Books (August 2000) and McCarthy, "Programmable Matter," Nature (05 October 2000). Detailed information about the composition, construction, or functioning of these devices is not given.

~~The first detailed and technically rigorous discussion of a quantum dot fiber occurs in Provisional Patent Application Ser.#60/312264, filed 13 August 2001 by myself. The Provisional Patent Application forms the basis of this patent application.~~

SUMMARY OF THE INVENTION

~~In accordance with the present invention, a quantum dot fiber comprises a fiber containing one or more control wires, which control quantum dots on the exterior surface of the fiber.~~

It is a general object of the present invention to use quantum dots to produce a plurality of real-time programmable dopants in materials. In one embodiment, an energy-transporting fiber is disclosed that controls the properties of quantum dot dopants using external energy sources, even when the dopants are embedded in solid materials, including

opaque or electrically insulating materials that would ordinarily isolate the quantum dots from external influences.

A programmable dopant fiber may be composed of a fiber-shaped material with a plurality of quantum dot particles or quantum dot devices populating the surface of the fiber. The fiber further contains one or more control paths, which carry energy to the quantum dots in order to control their confinement of charge carriers.

According to the present invention, charge carriers are driven into quantum confinement in the quantum dots by the energy in the control paths such that they form artificial atoms that serve as dopants for the surrounding materials. The atomic number of each artificial atom is adjusted through precise variations or modulations in the voltage across the quantum dot that confines it. This alters the doping characteristics of the artificial atoms.

In some embodiments of the present invention, the excitation level of the artificial atom is also controlled, either through additional electrical voltages or through optical or electromagnetic stimulation. Additionally, in some embodiments of the invention the energy in the control paths creates electric fields which affect the quantum confinement characteristics of the quantum dots, producing controlled and repeatable distortions in the size and shape of the artificial atoms, further altering their doping characteristics, with a corresponding effect on the surrounding materials. Since the electrical, optical, thermal, magnetic, mechanical, and chemical properties of a material depend on its electronic structure, and since the embedding of dopants can affect this structure, the programmable dopant fiber offers a means of controlling the interior properties of bulk materials in real time.

~~OBJECTS AND ADVANTAGES~~

~~Accordingly, several objects and advantages of the~~ The present invention ~~are:~~

~~(a) that it~~ provides a three-dimensional structure for quantum dots ~~which~~ that can be considerably more robust than a nanoparticle film. For example, a contiguous GaAs fiber or metal wire is held together by atomic bonds, as opposed to the much weaker Van der Waals forces which hold nanoparticle films together.

~~(b) that it~~ The present invention also provides a method for the electrical and/or optical stimulation of quantum dot particles embedded inside bulk materials. The fiber ~~can~~ may consist of, or include, one or more ~~metal~~ wires, ~~or~~ optical conduits, or other energy pathways that ~~which~~ are electrically and/or optically isolated from the material in which they are embedded. These pathways ~~can~~ branch directly to the ~~surfaces or interiors of the~~

quantum dot particles or devices on the surface of the fiber, providing the means to stimulate them.

~~(c) that is~~ The present invention further provides a method for embedding and controlling electrostatic quantum dot devices (and potentially other types of quantum dot devices) inside bulk materials, rather than at their surfaces.

~~(d) that it permits~~ With the present invention, the doping characteristics of quantum dots inside a material ~~to~~ can be controlled by external signals, and thus varied by a user at the time of use. Thus, the properties of the bulk material can be tuned in real time, in response to changing needs or circumstances.

~~(e) that~~ According to the present invention, the ~~quantum dot~~ programmable dopant fiber can be used outside of bulk materials, in applications where quantum dots, quantum wires, and nanoparticle films are presently used. For example, the ~~quantum dot~~ programmable dopant fiber can serve as a microscopic light source or laser light source ~~which~~ that is both long and flexible.

~~(f) that~~ Further, multiple ~~quantum dot~~ programmable dopant fibers can be arranged on a surface to produce two-dimensional materials analogous to nanoparticle films, but much stronger.

~~(g) that~~ Also, according to the present invention, multiple ~~quantum dot~~ programmable dopant fibers can be woven, braided, or otherwise arranged into three-dimensional structures whose properties can be adjusted through external signals, forming a type of "programmable matter." ~~which is~~ This programmable matter may be a bulk solid with electrical, ~~and~~ optical, ~~properties (and potentially other properties such as~~ thermal, magnetic, mechanical, and chemical properties[[)]] that can be tuned in real time through the adjustment of the energies in the control paths, which affect the properties of artificial atoms used as dopants.

~~(h) that the~~ The resulting programmable materials, unlike nanoparticle films, can contain artificial atoms of numerous and wildly different types, if desired. Thus, the number of potential uses for the ~~quantum dot~~ programmable dopant fiber materials is vastly greater than for the materials based on nanoparticle films.

~~**DRAWING FIGURES**~~

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, closely related figures have the same~~ number~~ element numbers~~ but different alphabetic suffixes~~, except for ~~figures~~ Figs. 1~~ and 2~~-3B from the prior art~~, which are closely related~~.

Figs. 1 and 2 are from the prior art, U.S. ~~patent~~ Patent No. 5,881,200 to Burt (1999), ~~showing an~~ and show a hollow optical fiber containing ~~a central opening filled with~~ a colloidal solution of quantum dots in a support medium.

Figs. 3a and 3b are from the prior art, U.S. ~~patent~~ Patent No. 5,889,288 to ~~Futasugi~~ Futatsugi (1999)~~, showing~~ and show a semiconductor quantum dot device ~~which~~ that uses electrostatic repulsion to confine electrons.

Figs. 4a and 4b are ~~from the~~ schematic drawings of a first embodiment of the present invention~~, in its preferred embodiment. This is a~~ detailing a multilayered microscopic fiber ~~which~~ that includes a quantum well, surface electrodes, which form quantum dot devices, and control wires to carry electrical signals to the electrodes.

Fig. 4c is a schematic drawing of an alternative to the embodiment of Figs. 4a and 4b including an optional memory layer.

Figs. 5a and 5b ~~disclose an additional~~ are schematic drawings of a second embodiment of the present invention, in which ~~the quantum dot devices (quantum well and electrodes) on the fiber's surface are replaced with~~ quantum dot particles are positioned on the surface of the fiber.

Figs. 6a and 6b ~~disclose a variant of this~~ are schematic drawings of a third embodiment, in which the fiber comprises a single control wire with quantum dot particles attached to its exterior surface.

Figs. 7a and 7b ~~disclose~~ are schematic drawings of still another alternative embodiment of the present invention~~, comprising~~ showing an ordered chain of quantum dot particles alternating with control wire segments.

~~**REFERENCE NUMERALS IN DRAWINGS**~~

~~Reference numerals for the prior art are not included here. The reference numerals for the present invention are as follows:~~

~~(30) Surface electrodes~~

~~(31) Positive layers of quantum well~~

~~(32) Negative layer of quantum well~~

~~(33) Memory layer, comprising microscopic transistors to switch electrodes on and off. This layer is optional, since this switching can be accomplished external to the fiber.~~

~~(34) Control wires~~

~~(35) Insulator~~

~~(36) Control wire branches to fiber surface~~

~~(37) Quantum dot particles~~

~~(38) Control wire segments~~

~~(QD) Quantum dot region~~

~~Please note that Figures 1-3 are from the prior art, and are included for reference in the Prior Art section of this specification. To prevent confusion, the figures for the present invention, in the drawing pages below, are numbered 4 and above.~~

~~**DESCRIPTION -- FIGS. 4a and 4b -- PREFERRED EMBODIMENT**~~

DETAILED DESCRIPTION OF THE INVENTION

Figures 4a (isometric view) and 4b (end view) show a preferred embodiment of the invention, which is a fiber containing control wires (34) in an insulating medium (35), surrounded by ~~layers of semiconductor or other materials (31) and (32) which form~~ a quantum well, plus an optional memory layer (33). The preferred composition of the insulator (35) is a semiconductor oxide, although a variety of other materials could be used. The preferred composition of the quantum well is a central or transport layer (32) of a semiconductor (similar to the negative layer of a P-N-P junction), for example, GaAs, surrounded by barrier or supply layers (31) of a semiconductor with higher conduction energy (similar to the positive layers of a P-N-P junction). Because of the difference in conduction energies, electrons "fall" preferentially into the lower energy of the transport layer (32), where they are free to travel horizontally (that is, within the layer) but are confined vertically (perpendicular to the layer) by the higher conduction energy of the barrier layers. However, the present invention is not limited to this particular configuration, and includes quantum wells made from other materials and with other designs, as well as quantum wells designed to trap "holes" or other charge carriers.

The ~~central~~ transport layer (32) of the quantum well must be smaller in thickness than the de Broglie wavelength of the charge carriers for the charge carriers to be confined in it. For an electron at room temperature, this would be approximately 20 nanometers. Thicker quantum wells are possible, although they will only ~~operate~~ exhibit quantum confinement of the charge carriers at temperatures colder than room temperature. Thinner quantum wells

will operate at room temperature, and at higher temperatures so long as the de Broglie wavelength of the carriers does not exceed the thickness of the ~~confinement~~ transport layer (32).

The surface of the fiber includes conductors ~~which~~ that serve as the electrodes (30) of a quantum dot device~~, which~~. These electrodes (30) confine charge carriers in the quantum well into a small space or quantum dot (QD)~~, forming an artificial atom~~ when a reverse-bias voltage is applied, since the negative charge on the electrodes (30) repels electrons, preventing their horizontal escape through the transport layer. The electrodes (30) are powered by control wire branches (36) reaching to the surface of the fiber from the control wires (34) ~~to the fiber's surface~~ in the fiber's center. In the preferred embodiment, ~~The~~ the electrodes (30), control wires (34), and control wire branches ~~would normally be electrical conductors~~ (36) are made of gold, although in principle they could be made of other metals, or other materials, such as semiconductors or superconductors.

Once the charge carriers are trapped in a quantum dot (QD), they form an artificial atom that is capable of serving as a dopant. Increasing the voltage on the electrodes (30) by a specific amount forces a specific number of additional carriers into the quantum dot (QD), altering the atomic number of the artificial atom trapped inside. Conversely, decreasing the voltage by a specific amount allows a specific number of carriers to escape to regions of the transport layer (32) outside the quantum dot (QD). One embodiment of the invention shown in Fig. 4a provides six electrodes (30) for each quantum dot device (QD), although more or less could be used. By selecting the voltages applied to these electrodes (30) it is possible to alter the repulsive electric field, thus affecting size and shape of the quantum dot (QD) confinement region. Changes to the confinement region similarly alter the size and shape of the artificial atom trapped inside the quantum dot (QD), either in conjunction with changes to the artificial atom's atomic number or while holding the atomic number constant. Thus, the doping properties of the artificial atom are adjusted in real time through variations in the signal voltage of the control wires (34) at the center of the fiber.

There are various possibilities for making the programmable dopant fiber of different materials, and in different configurations. The most advantageous configurations are the smallest, since smaller quantum dots can contain charge carriers at higher energies (shorter de Broglie wavelengths) and thus display atom-like behavior at higher temperatures. The smallest conceivable programmable dopant fiber would be similar in design to the single-electron transistor described in Goldhaber-Gordon et al., although molecules the size of benzene rings or smaller, if employed as quantum dot particles, will be unable to hold large

numbers of excess charge carriers. This limits their usefulness in generating artificial atoms. A somewhat larger but more practical design is to employ electrically conductive nanotubes, such as a carbon nanotubes, as the control wire segments (34), and fullerene-type molecules, such as carbon fullerenes (for example, the quantum dot particles (37) of Figs. 5a and 5b).

Figure 4c shows the optional ~~The~~ memory layer (33), ~~comprises~~ which may be formed of microscopic transistors or other switches placed inline with the control wire branches (36) ~~which serve as switches, and which~~ that are capable of turning voltages to the surface electrodes (30) on and off. The ends of the control wire branch (36) may serve as the source and drain electrodes of the switch, and an additional control wire branch (36) is extended from a central control wire (34) to serve as the gate electrode for the switch. The switch may be a field effect transistor, although numerous other types of switches may be used without affecting the function of the invention. This switching or memory layer is optional, since this switching can be accomplished external to the fiber. However, it is included here for clarity. However, the present invention should not be limited to this particular configuration, and may include quantum dot devices made of other materials or of alternative designs, including devices protected by an additional insulating layer (not pictured), either continuous or discontinuous, on top of the electrodes (30) at the surface of the fiber.

Note that the exact arrangement of the various layers can be slightly different than ~~is~~ depicted here[[,]] without altering the essential functioning of the ~~quantum dot~~ programmable dopant fiber. For example, the cross-section may be any oval or polygon shape, and the ~~inslulated~~ insulated control wires (34) need not be located at the fiber's center, although that ~~seems to~~ may be the most convenient place to locate them.

The preferred manner of using the programmable dopant fiber is to place the fiber or a plurality of fibers, as needed, inside a bulk material (e.g., a semiconductor), or to weave or braid them together into a two- or three-dimensional structure. Barrier layers (31) and transport layer (32) form a quantum well, which traps charge carriers in a quantum (wavelike) manner in the central or transport layer (32).

An electrical potential is then applied across the quantum wells through the control wires (34) from an external source. Energy motivated by the applied voltage flows from the control wires (34) to the control wire branches (36) and then to electrodes (30) on the surface of the fiber. Alternatively, the control wire branches (36) may pass through the optional memory layer (33). The memory layer (33) may be composed of in-line transistors or other switches, embedded in an insulating medium, which are capable of switching the electrical

pathways open or closed. From the memory layer (33), the control wire branches (36) then lead to the electrodes (30) at the surface of the fiber. Once the electrical potential is applied across the electrodes (30), the change in voltage creates an electrostatic repulsion that affects the carriers trapped in the quantum well, herding them into small areas known as quantum dots where they form artificial atoms.

Adjustment of the voltages across the electrodes (30) can then affect the characteristics of the artificial atoms, including: size; shape or symmetry; number of charge carriers; and energy levels of the carriers. The resulting changes in the artificial atom can dramatically affect its properties as a dopant.

Depending on the number of control wires (34) inside the fiber and the number of quantum dot devices (QD) along its surface, the artificial atoms created in the confinement layer (32) may all be identical, may represent multiple "artificial elements" in regular or irregular sequences, or may all be different. For example, if the signals sent to each quantum dot device (QD) were identical, the artificial atoms on the fiber might all have an atomic number of 2, equivalent to helium, which would otherwise be extremely difficult to introduce as a dopant. Conversely, if two separate sets of control signals were sent, the artificial atoms could be an alternating pattern of helium (atomic number 2) and carbon (atomic number 6).

~~FIGS 5a-7b — ADDITIONAL EMBODIMENTS~~

Figures 5a (isometric view) and 5b (end view) show an additional embodiment of the invention, in which the fiber comprises multiple control wires (34) surrounded by insulation (35), with control wire branches (36) leading to quantum dot particles (37) on the surface of the fiber. ~~For clarity, an~~ An optional memory layer ~~(33) is~~ (not shown) may be included in the fiber of this embodiment as well. In this embodiment, the control wires ~~could be~~ are conductors, but they could also be semiconductors, or superconductors, ~~but could also be~~ optical fibers, or other types of conduits for carrying energy to stimulate the quantum dot particles (37). ~~Again, the~~ The dimensions can cover a broad range of microscopic values while retaining useful optical, electrical, and other properties for the ~~quantum dot~~ programmable dopant fiber.

Because they are easily self-assembled in chemical solutions, the quantum dot particles (37) may be spherical nanocrystals consisting of a core of semiconductor material surrounded by a passivating shell of crystalline organic material. Dimensions of the core should not exceed the de Broglie wavelength of the carriers to be confined within it. However, the invention is not limited to this particular configuration, and may include

quantum dot particles of other shapes or made using other materials and methods. Quantum dot particles may be deposited onto the fiber, for example, by evaporation. Attachment to the fiber is readily accomplished by means of van der Waals forces, although active "molecular tethers" may be added to the shell and/or fiber in order to bond the quantum dot particle (37) chemically to the insulator (35) or to the control wire branches (36).

The operation of this embodiment is very similar to the embodiment of Figs. 4a-4c, with the exception that the carriers are confined in quantum dot particles (37) rather than by electrostatic repulsion and a quantum well. Electrical (or optical) energy is applied to the control wires (34) from an external source, and further to the surface of the fiber via control wire branches (36). An electrical potential is then created across the quantum dot particles (37). Placing the fiber adjacent to a grounded conductive or semiconductive material, including another programmable dopant fiber, produces a ground path from the control wire branches (36) and then through the quantum dot particles (37). This creates the electrical potential across the quantum dot particles (37) and forces the charge carriers into quantum confinement inside them, where they form artificial atoms. Increasing the voltage across the control wires (34) drives additional carriers into the quantum dot particles (37), increasing the atomic number of the artificial atoms inside them.

Additionally, electrical or optical energy passed through the control wires (34) can increase the excitation level of the artificial atoms. This stimulation can thus affect the properties of the artificial atoms contained in the quantum dot particles (37), including the number of carriers and the energy levels of the carriers. As before, the resulting changes in the artificial atom can dramatically affect its properties as a dopant.

Depending on the number of control wires inside the fiber and the number of quantum dot particles along its surface, the artificial atoms located in the quantum dot particles may all be identical, may represent multiple "artificial elements" in regular or irregular sequences, or may all be different. In the case of the specific embodiment shown in Figures 5a and 5b, there are four control paths. Therefore, each quarter-arc of the surface of the fiber may receive different control signals and display different doping characteristics. Thus, the fiber may have up to four "stripes" of different dopant running along its length.

Figures 6a (isometric view) and 6b (end view) show another additional embodiment, in which quantum dot particles (37) are attached to the surface of a non-insulated control wire (34). In general, this wire ~~would~~ may be an electrical conductor, ~~semiconductor, or superconductor,~~ but could ~~in principle~~ be another type of ~~conduits~~ conduit for carrying energy

to stimulate the quantum dot particles, for example, a semiconductor, superconductor, or optical fiber. Dimensions can once again cover a broad range of microscopic values.

Because they are easily self-assembled in chemical solutions, the quantum dot particles (37) may be spherical nanocrystals consisting of a core of semiconductor material surrounded by a passivating shell of crystalline organic material. Dimensions of the core should not exceed the de Broglie wavelength of the carriers to be confined within it. However, the invention is not limited to this particular configuration, and may include quantum dot particles (37) of other shapes or made using other materials and methods. Quantum dot particles (37) may be deposited onto the fiber, for example, by evaporation. Attachment to the fiber is readily accomplished by means of van der Waals forces, although active "molecular tethers" may be added to the shell and/or fiber in order to bond the quantum dot particle (37) chemically to the control wire (34).

The operation of this embodiment is similar to that of Figures 5a and 5b, with the exception that the fiber comprises a single control wire (34), with quantum dot particles (37) attached to its outer surface. Once again, the quantum dot particles (37) are stimulated by a current (or optical energy) passing through the control wire (34) to a ground path that includes the quantum dot particles (37). This creates a voltage across the quantum dot particles (37) and forces the charge carriers into quantum confinement inside them, where they form artificial atoms. Increasing the voltage across the control wire (34) drives additional carriers into the quantum dot particles (37), increasing the atomic number of the artificial atoms inside them.

This stimulation can then affect the properties of the artificial atoms contained in the quantum dot particles, including the number of carriers and the energy levels of the carriers. As before, the resulting changes in the artificial atom can dramatically affect its properties as a dopant. The capabilities of this embodiment are more limited, in that (barring minor variations in the size and composition of the quantum dot particles (37)) all the artificial atoms along the fiber cannot be controlled separately or in subgroups, and will therefore have the same characteristics. No controlled patterning of different artificial dopant species is possible, except at the time of manufacture.

Figures 7a (isometric view) and ~~6b~~ 7b (end view) show still another additional embodiment, in which ~~the fiber comprises multiple~~ control ~~wires (34) surrounded by insulation (35), with control wire branches (36) leading to~~ wire segments (38) alternate with quantum dot particles (37)~~ on the surface of the fiber. For clarity, an optional memory layer (33) is included as well. In this embodiment the control wires could be conductors,~~

~~semiconductors, or superconductors, but could also be optical fibers, or other types of conduits for carrying energy to stimulate the quantum dot particles (37). Again the~~ The dimensions ~~can~~ of both the control wire segments (38) and the quantum dot particles (37), while generally microscopic, could cover a broad range of values while retaining useful optical, electrical, and other properties for the ~~quantum dot~~ programmable dopant fiber.

The operation of this embodiment is similar to that of Figures 6a and 6b, with the exception that the quantum dot particles (37) are not attached to the surface of the fiber, but are an integral part of its structure, alternating with control wire segments (38). Because they are easily self-assembled in chemical solutions,the quantum dot particles (37) may be spherical nanocrystals consisting of a core of semiconductor material surrounded by a passivating shell of crystalline organic material. Dimensions of the core should not exceed the de Broglie wavelength of the carriers to be confined within it. Control wire segments (38) may be metallic and bonded chemically to "molecular tethers" on the quantum dot particles (37). However, the invention is not limited to this particular configuration, and may include quantum dot particles (37) and control wire segments (38) made and joined using other materials and methods, including the molecular wires and quantum dots described by Goldhaber-Gordon et. al.

Electrical (or optical) energy may be applied to the control wire segments (38) and directly to the quantum dot particles (37), stimulating them as described above. This stimulation can then affect the properties of the artificial atoms contained in the quantum dot particles (37), including the number of carriers and the energy levels of the carriers. As before, the resulting changes in the artificial atom can dramatically affect its properties as a dopant.

The capabilities of this embodiment are even more limited than the previous one, in that resistive losses across each quantum dot particle (37) will cause the voltage to drop significantly across each segment of the fiber. Thus, each successive artificial atom along the length of the fiber will have a lower voltage (or, for example, illumination) than the one before it. Thus, the artificial atoms cannot be individually controlled and will not be identical. Instead, the user may select a sequence of artificial elements, of successively lower energies, to be presented by the fiber. For example, the fiber might contain a number of artificial atoms bearing atomic number 6, followed by a number bearing atomic number 5, and so on. This is far from the ideal form of a programmable dopant fiber, but it does provide a unique doping capability.

~~**ALTERNATIVE EMBODIMENTS**~~

~~There are various possibilities for making the quantum dot fiber of different materials, and in different configurations. The most advantageous configurations are the smallest, since smaller quantum dots can contain charge carriers at higher energies and thus display atom-like behavior at higher temperatures. The smallest conceivable quantum dot fiber would be similar in design to the single-electron transistor described in Goldhaber-Gordon et. al (1997), although molecules the size of benzene rings or smaller, if employed as quantum dot particles, will be unable to hold large numbers of excess charge carriers. This limits their usefulness in generating artificial atoms. A somewhat larger but more practical design is to employ electrically conductive nanotubes, such as a carbon nanotubes, as the control wire segments (38), and fullerene-type molecules, such as carbon fullerenes, as the quantum dot particles (37).~~

~~**ADVANTAGES**~~

From the description above, ~~our quantum dot~~ the programmable dopant fiber can be seen to provide a number of ~~cabailities which~~ capabilities that are not possible with the prior art[[:]]. ~~(a) The~~ First, the present invention provides the ability to place programmable dopants in the interior of bulk materials~~.~~

~~(b) The ability~~ and to control the properties of these dopants in real time, through external signals. In contrast, the properties of dopants based solely on quantum dot particles can only be controlled at the time of manufacture.

~~(c) The~~ Second, the present invention provides the ability to form programmable materials containing "artificial atoms" of diverse types. In contrast, programmable materials based on nanoparticle films can contain only multiple instances of one "artificial element" at a time.

Also from the above description, several advantages over the prior art become evident[[:]]. First,

~~(c) Materials~~ materials based on ~~quantum dot~~ programmable dopant fibers will, in general, be much stronger than materials based on nanoparticle films.

~~(d) Quantum dot~~ Second, programmable dopant fibers can be used in numerous applications where quantum dots and quantum wires are presently employed. However, the ~~quantum dot~~ programmable dopant fiber provides isolated energy channels for the optical or electrical stimulation of the quantum dots, permitting the quantum dots to be excited without also affecting the surrounding medium or materials. For example, light can be passed through a quantum dot by means of the fiber, without also being shined on or through

surrounding areas, except through the fiber itself. Similarly, an electrical voltage can be ~~channeled to~~ placed across a quantum dot without passing through the surrounding medium, except through the fiber. Thus, ~~quantum dot~~ programmable dopant fibers can be used in numerous applications where ordinary quantum dot devices or particles would ~~prove disruptive~~ not operate, or would disrupt the surrounding material in uncontrolled ways.

~~**OPERATION -- FIGS 4a and 4b**~~

~~The preferred manner of using the quantum dot fiber is to place a fiber or a plurality of fibers, as needed, inside a bulk material (e.g., a semiconductor), or to weave or braid them together into a two or three-dimensional structure. Material layers (31) and (32) form a quantum well, which traps charge carriers in a quantum (wavelike) manner in the central layer (32).~~

~~Voltages (or other energy if appropriate) are then passed through the control wires (30) from an external source. These voltages pass from the control wires to the control wire branches (36), where they are carried to electrodes (30) on the sufrace surface of the fiber. Alternatively, the control wire branches may pass through an optional memory layer (33) which consists of transistors or other switches which are capable of switching the voltage pathways open or closed. From the memory layer, the control wire branches would then lead to the electrodes at the surface of the fiber. Once the voltage reaches the electrodes, it creates an electrostatic repulsion which affects the carriers trapped in the quantum well, herding them into small areas known as quantum dots, where they form artificial atoms.~~

~~Adjustment of the voltages on the electrodes can then affect the characteristics of the artificial atoms, including:~~

~~(a) size~~
~~(b) shape or symmetry~~
~~(c) number of charge carriers~~
~~(d) energy levels of the carriers~~

~~The resulting changes in the artificial atom can dramatically affect its properties as a dopant.~~

~~Depending on the number of control wires inside the fiber and the number of quantum dot devices along its surface, the artificial atoms located near the fiber's surface (in the confinement layer 32) may all be identical, may represent multiple "artificial elements" in regular or irregular sequences, or may all be different.~~

~~**OPERATION -- FIGS 5a and 5b**~~

~~The operation of this embodiment is very similar to the previous one, with the exception that the carriers are confined in quantum dot particles (37) rather than by electrostatic repulsion and a quantum well. Voltages (or optical energy or other energy) are passed through the control wires (34) from an external source, and brought to the fiber's surface via control wire branches (36). These voltages are then carried to the quantum dot particles, in order to stimulate them. This stimulation can then affect the properties of the artificial atoms contained in the quantum dot particles, including:~~

~~(a) number of carriers~~

~~(b) energy levels of the carriers~~

~~As before, the resulting changes in the artificial atom can dramatically affect its properties as a dopant.~~

~~Depending on the number of control wires inside the fiber and the number of quantum dot particles along its surface, the artificial atoms located in the quantum dot particles may all be identical, may represent multiple "artificial elements" in regular or irregular sequences, or may all be different.~~

~~OPERATION — FIGS 6a and 6b~~

~~The operation of this embodiment is similar to the previous one, with the exception that the fiber comprises a single control wire (34), with quantum dot particles (37) attached to its outer surface. The quantum dots are stimulated by voltage (or optical energy or other energy) passing through the control wire. This stimulation can then affect the properties of the artificial atoms contained in the quantum dot particles, including:~~

~~(a) number of carriers~~

~~(b) energy levels of the carriers~~

~~As before, the resulting changes in the artificial atom can dramatically affect its properties as a dopant.~~

~~The capabilities of this embodiment are more limited, in that (barring minor variations in the size and composition of the quantum dot particles) all the artificial atoms along the fiber will have the same characteristics. In some cases it may be necessary to place a high impedance in series with the fiber's control wire in order for a voltage to drive charge carriers into the quantum dots.~~

~~OPERATION — FIGS 7a and 7b~~

~~The operation of this embodiment is similar to the previous one, with the exception that the quantum dot particles (37) are not attached to the surface of the fiber, but are an integral part of its structure, alternating with control wire segments (38). A voltage (or optical energy or other energy) is passed through the control wire, and passes directly into and through the quantum dot particles, stimulating them. This stimulation can then affect the properties of the artificial atoms contained in the quantum dot particles, including:~~

~~(a) number of carriers~~

~~(b) energy levels of the carriers~~

~~As before, the resulting changes in the artificial atom can dramatically affect its properties as a dopant.~~

~~The capabilities of this embodiment are even more limited than the previous one, in that resistive losses across each quantum dot particle will cause the voltage to drop significantly across each segment of the fiber. Thus, each successive artificial atom along the fiber's length will have a lower voltage (or illumination or other excitation) than the one before it. Thus, the artificial atoms cannot be individually controlled and will not be identical. Instead, the user may select a sequence of artificial elements, of successively lower energies, to be presented by the fiber.~~

~~CONCLUSION, RAMIFICATIONS, AND SCOPE~~

Accordingly, ~~the reader will see~~ it should be recognized that the ~~quantum dot~~ programmable dopant fiber of this invention can be used as a real-time programmable dopant inside bulk materials, as a building block for new materials with unique properties, and as a substitute for quantum dots and quantum wires in various applications (e.g., as a light source or laser light source).

Although the description above contains ~~many specificities~~ much specificity, ~~these~~ this should not be construed as limiting the scope of the invention but merely as providing illustrations of some of the presently preferred embodiments of this invention. Numerous other variations may exist which do not affect the core principles of the invention's operation. For example, the fiber could have non-circular shapes in cross-section, including a flat ribbon with quantum dots on one or both sides; the "artificial atoms" could be composed of charge carriers other than electrons[[,]]; the control wires could be replaced with semiconductor, superconductor, optical fiber, or other conduits for carrying energy; the control wires could be antennas for receiving signals and energy from electromagnetic waves; any of the embodiments listed here could be replicated on a molecular scale through the use of

specialized molecules such as carbon nanotube wires and fullerene quantum dot particles; the quantum dots could be other sorts of particles or devices than those discussed herein, so long as they accomplish the quantum confinement necessary for the formation of artificial atoms; and the number and relative sizes of the quantum dots with respect to the fiber could be significantly different than is shown in the drawings.

Thus the scope of the invention should be determined by the appended claims and their legal equivalents, rather than by the examples given.

CLAIMS: ~~I~~ We claim:

1. In a device for producing quantum effects, comprising:

(a) a material fashioned into an elongated fiber shape, as in a wire, ribbon, or optical fiber;

(b) one or more control paths which carry energy along said fiber;

(c) quantum dots, whether particles, devices, or other types, on or near the surface of the fiber, which trap and hold a configuration of charge carriers based on the energy or energies in said control paths, thus forming artificial atoms \

whereby said fiber can serve as a substitute for quantum dots and quantum wires in existing and future applications, and

whereby the electrical, optical and possibly other properties such as magnetic, mechanical, and chemical properties of said fiber can be manipulated through adjustment of the energies in the control paths, and

whereby said fiber can be embedded inside a bulk material, to serve as a programmable dopant which is capable of altering the electrical, optical and possibly other properties of said material in real time based on the energies in said control paths, and

whereby a plurality of said fibers can be woven, braided, or otherwise arranged into two- or three-dimensional structures, creating materials whose characteristics are electrically or optically programmable in real time by means of the energies in said control paths.

2. The device of Claim 1 wherein said control paths are electrical wires, whether conductors, semiconductors, or superconductors, which carry electrical voltages.

3. The device of Claim 1 wherein said control paths are optical fibers carrying light or laser energy.

4. The device of Claim 1 wherein said control paths are radio frequency or microwave antennas.

5. The device of Claim 1 wherein the quantum dots are quantum dot particles

6. The device of Claim 1 wherein the quantum dots are quantum dot devices

7. In a method for controlling dopants in the interior of bulk materials, comprising:

(a) confining charge carriers in a dimension smaller than the de Broglie wavelength of said carriers, such that the carriers assume a quantum wavelike behavior in all three dimensions

(b) carrying electrical or other energy through conduits to said carriers while embedded in a solid material, without said energy directly contacting said material except through said carriers

whereby said carriers form configurations such as artificial atoms whose properties are controlled in real time, and which are capable of serving as programmable dopants to alter the electrical, optical, and possibly other properties such as thermal, magnetic, mechanical, and chemical properties~~,~~ of said material in real time, and

whereby a plurality of said methods can be combined, creating a means for producing materials whose electrical, optical, and possibly other properties such as magnetic, mechanical, and chemical properties can be adjusted in real time.

8. The method of Claim 6 wherein the means of confining said charge carriers is a plurality of quantum dot particles or quantum dot devices, and said conduits are consolidated into fibers to which said quantum dot particles or quantum dot devices are attached.

~~QUANTUM DOT FIBER~~

Abstract[[:]] ~~A fiber of microscopic diameter, having~~ A programmable dopant fiber includes a plurality of quantum structures formed on a fiber-shaped substrate, wherein the substrate includes one or more energy-carrying control paths (34), possibly surrounded by an ~~insluator~~ insulator (35), which pass energy to ~~the~~ quantum structures. Quantum structures may include quantum dot particles (37) on the surface of the fiber or electrodes (30) on top of barrier layers (31) and transport layer (32) which form quantum ~~dots~~ dot devices (QD)~~, or to quantum dot particles (37) on the fiber's surface~~. The energy passing through the ~~wires stimulates~~ control paths (34) drives charge carriers into the quantum dots (QD), leading to the formation of "artificial atoms" with real-time tunable properties. These artificial atoms then serve as programmable dopants, which alter the behavior of surrounding materials. The fiber can be used as a programmable dopant inside bulk materials, as a building block for new materials with unique properties, or as a substitute for quantum dots or quantum wires in certain applications.